AD-A146 290   DEVELOPMENTS IN FAR-INFRARED DETECTION TECHNIQUES(U)   1/1
              FOREIGN TECHNOLOGY DIV WRIGHT-PATTERSON AFB OH
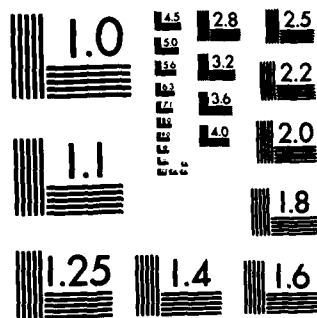   K FANPING ET AL. 06 AUG 84 FTD-ID(RS)T-0851-84

UNCLASSIFIED   F/G 17/5   NL

END
FILMED

DTIC

||| 1.0   4.5   2.8   2.5

||| 5.0   3.2   2.2

||| 5.6   3.6

||| 1.1   6.3   4.0   2.0

||| 1.8

||| 1.25 ||| 1.4 ||| 1.6

MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS-1963-A

AD-A146 290

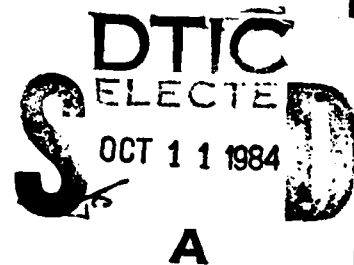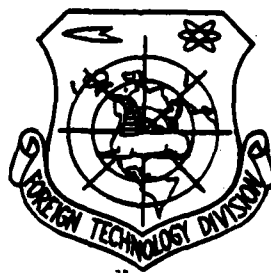# FOREIGN TECHNOLOGY DIVISION

DEVELOPMENTS IN FAR-INFRARED DETECTION TECHNIQUES

by

Kong Fanping and Lu Yongxiang

DTIC FILE COPY

DTIC
ELECTE
OCT 1 1 1984
A

84 08 30 089

EDITED TRANSLATION

FTD-ID(RS)T-0851-84   6 August 1984

MICROFICHE NR: FTD-84-C-000780

DEVELOPMENTS IN FAR-INFRARED DETECTION TECHNIQUES

By: Kong Fanping and Lu Yongxiang

English pages: 16

Source: Wuli, Vol. 12, Nr. 10, October 1983,
         pp. 598-603

Country of origin: China
Translated by: LEO KANNER ASSOCIATES
                F33657-81-D-0264
Requester: FTD/TQTR
Approved for public release; distribution unlimited.

A1

GRAPHICS DISCLAIMER

All figures, graphics, tables, equations, etc. merged into this
translation were extracted from the best quality copy available.

DEVELOPMENTS IN FAR-INFRARED DETECTION TECHNIQUES

Kong Fanping and Lu Yongxiang
The Shanghai Technical Physics Institute, Academia Sinica

I. Introduction

The far-infrared spectral region of wavelengths in the
electromagnetic wave spectrum located between infrared and
microwaves (wavelengths of 30 micron to 3 millimeters) is an
important transition region and many important physical pro-
cesses are closely related to the radiation phenomena of this
spectral region. For example, the pure rotation spectrum with
mostly light molecules and the absorption phenomena related to
the lattice vibration in solids and other elemenetary excita-
tion processes occur in this spectral region; the electron
cyclotron radiation of magnetically-confined plasma under high
temperature conditions is also in this region which is the major
part of the fusion plasma's energy dissipation formed from these
radiations. Aside from these, the astronomy research topics of
3K cosmic background radiation, and the cold celestial bodies,
interstellar dust and nebular molecule fine structures etc. of
the Milky Way system and extragalactic galaxy, which have
caught people's attention are inseparable from far-infrared de-
tection techniques. From the point of view of application tech-
niques, this spectral region has many special features and it
blends the principles of traditional microwave techniques and
geometric optics.

Because the far-infrared region has wide scientific and
technical utilization prospects, it has always received the
serious attention and solicitude of scientific workers from
various nations. Early, at the end of the nineteenth century,
taking Rubens as the representative, German scientists began
early investigative research on the far-infrared spectral
region [1]. However, because there was a lack of ideal

1

radiation sources and sufficiently sensitive detection devices, the advancements in development research on this spectral region were slow.

From the course of development of infrared and microwave science and technology, people clearly saw that in the research on the production and transmission of electromagnetic radiation and their interaction with substances, sensitive detecting devices play an especially important role. This is especially true of far-infrared radiation which cannot be directly sensed by the human sense organs but people must rely on special sensing elements to transform the far-infrared radiation energy into other physical quantities. It can be said that before the development of sensitive detecting elements, the wide application of far-infrared radiation was impossible. Far-infrared detection is also related to the problems of the effective transmission and coupling of radiation. This is related to the energy weakness of the radiation awaiting detection and the serious atmospheric attenuation. Therefore, conventional microwaves and optical techniques encounter difficulties.

This paper mainly introduces the developments in far-infrared detecting devices and in passing explains the transmission method and coupling structure etc. problems closely related to detectors.

II. Detection Mechanisms

Based on the different forms of interaction between far-infrared radiation and substances, far-infrared detectors can generally be divided into the three major categories of thermal detectors, photoconductive detectors and transprectification detectors. The first two devices were developed on the basis of optical and infrared detectors and the third type directly shifts the response spectrum region of the microwave detecting device towards even shorter wavelength areas.

2

1. The Thermal Detector

The thermal detector is the earliest used far-infrared
detecting device. It was made based on the thermal effects of
far-infrared radiation. As regards the structure of the de-
vice, there are generally two parts: the absorbent material can
absorb far-infrared radiation and the thermometer which is used
to indiciate the absorbing temperature rise. In order to raise
the sensitivity of the thermal detector and maintain excellent
transient response characteristics, the absorbent material of
the thermal detector and the thermal inertia of the thermometer
both have relatively small control. They are joined by certain
thermal resistance and constant temperature sources (the sur-
rounding environment). The response spectrum of the thermal
dedetector is determined by the absorbent material and window
material and the noise characteristics are determined by the
combinbination of the thermometers, thermal inertia, thermal
resistance and operating temperature.

The response characteristics of the thermal detector can be
analyzed beginning from the common thermal balance equation.
Assuming the thermal capacity of the thermal detector (the pro-
duct of the specific heat and mass) is H, the thermal conduction
between it and the constant temperature source is G and the
temperature difference is θ , then

$$\eta I = H d\theta/dt + G\theta, \qquad (1)$$

The I here is the power of the received irradiation on the de-
tector and η is the absorption efficiency. If the irradiation
power of incidence is sinusoidal range modulated, that is
$I = I_\omega e^{j\omega t}$, at this time, the changes of θ are also sinusoidal.
Moreover, $\theta = \theta_\omega e^{j(\omega t + \phi)}$. Here, θ_ω and ϕ separately
satisfy

$$\theta_\omega = \eta I_\omega (G^2 + \omega^2 H^2)^{-\frac{1}{2}}, \qquad (2)$$

$$\phi = \text{arc } \tan(\omega H/G). \qquad (3)$$

Because θ_ω is actually the maximum temperature rise after the
absorbent material sustains irradiation, we can see from form-
ulas (2) and (3) that decreasing thermal conduction G and
decreasing modulation frequency ω of the incident radiation
(causing $\omega H \ll G$) is helpful to raising the speed of response
of the thermal detector.

There are many types of commonly used thermal detectors: the
pneumatic Gaolai tube, thermopile, thermoelectric detector as
well as the refrigeration type resistance radiation thermometer
etc. The Gaolai tube uses thin metallic film as the absorbent
material and after the quantity of heat which it absorbed is
transfered to the gas in the Gaolai tube, the pressure of the
gas correspondingly increases which causes the organic film of
the rear wall to expand and the relaxation of the organic film
to be directly read out by the optical method. The structure
of the thermopile is strong, its performance is stable, its
bearing power is high and it often acts as the basis for far-
infrared spectral region power calibration. The detector which
developed most rapidly in recent years is the thermoelectric
detector. This device is made from magneto-electric material
which possesses spontaneous polarization characteristics and the
output signals form a direct ratio with the rate of change of
the material's temperature rise (but it is not the temperature
rise itself). Therefore, it possibly shortens the response
time to the nanosecond level and the utilization range expands
with it. The refrigeration type resistance radiation thermo-
meter is already commonly used in the far-infrared spectral
region. Because the operating temperature is low and the noise
in the device related to the temperature and its own emission
both decrease, the response performance is very good. At
present, the synthetic type resistance radiation thermometer
is being developed to expand the range of the response spectral
region. See Table 1 for the development levels of the various
types of thermal detectors.

4

(1) 种 类	(7)响应波长范围	响 应 率 (13)	响应时间（或调制频率范围）(19)	噪声等效功率 NEP (25)
(2) 热电堆(室温)	$\lambda < 50$ 微米 (8)	10^{-1}—10^1伏·瓦$^{-1}$ (14)	10^{-1}—10秒 (20)	10^{-9}瓦·赫$^{-\frac{1}{2}}$ (26)
(3) 高莱管(室温)	取决于窗口材料 (9)	10^3—10^4伏·瓦$^{-1}$ (15)	5—20赫 (21)	10^{-10}瓦·赫$^{-\frac{1}{2}}$ (商品) (27)(31)
(4)热释电探测器(室温)	取决于探测材料和窗口材料 (10)	10^3—10^6伏·瓦$^{-1}$ (16)	10^{-9}秒 (22)	5×10^{-10}瓦·赫$^{-\frac{1}{2}}$ (28)
(5) ^{4}He 致冷的半导体测辐射热计 (1.2K)	取决于探测材料、涂层和窗口材料 (11)	10^3—10^9伏·瓦$^{-1}$ (17)	5—100毫秒 (23)	10^{-12}—10^{-13}瓦·赫$^{-\frac{1}{2}}$ (29)
(6) ^{3}He 致冷的半导体测辐射热计 (0.3K)	取决于探测材料、涂层和窗口材料 (12)	10^9伏·瓦$^{-1}$ (18)	5—100毫秒 (24)	10^{-14}—10^{-16}瓦·赫$^{-\frac{1}{2}}$ (30)

Table 1   Performance of typical thermal detectors [2].

> Key: (1) Type; (2) Thermopile (room temperature;
> (3)Gaoli tube (room temperature); (4) Thermo-
> electric detector (room temperature);
> (5) ^{4}He refrigerated semiconductor radiation
> thermometer ; (6) ^{3}He refrigerated semiconductor
> radiation thermometer; (7) Response wavelength
> range; (8) Micron; (9) Determined by window
> material; (10) Determined by detecting material
> and window material; (11)-(12) Determined by
> detecting material, coating material and window
> material; (13) Speed of response; (14)-(18) Volts·
> watts; (19) Response time (or modulation fre-
> quency range); (20) Seconds; (21) Hertz;
> (22) Seconds; (23)-(24) Milliseconds; (25) Noise
> Equivalent power; (26)-(30) Watts·hertz;
> (31) Commodity.

2.   The Photoconductive Detector

The photoconductive detector is made based on the electro-
conductive changes caused by the direct effects of electromag-
netic radiation and detecting materials. Because this type of
photoconductive effect is always connected to certain excita-
tion processes of electrons in the detecting material, the
detecting process often has long wave cut-off characteristics.
As regards the widening involvement of the non-intrinsic photo-
conductive process in far-infrared detection applications, the
energy of the far-infrared radiation quantum awaiting

measurement must be larger than the detecting material's cor-
responding energy level distance E_i, that is

$$h\nu = hc/\lambda \geqslant E_i, \qquad (4)$$

Here, h is the Planck's constant, ν is the radiation frequency,
c is the speed of light, λ is the radiation wavelength and E_i
is the impurity activation energy in the non-intrinsic semi-
conductor material. From formula (4), we can also directly
obtain cut-off wavelength λ_c of the photoconductive process:

$$\lambda_c = hc/E_i. \qquad (5)$$

In the semiconductor detectors, the speed of the photon-
generated carriers produced by the incident electromagnetic
radiation is $I\alpha\beta$. Within this, I indicates the incident
radiation intensity (using the photon number as the unit), α
is the absorption coefficient and β is the quantum yield. By
using various mechanisms and compound carriers, the compound
rates can statistically be indicated as $\Delta n/\tau$ with τ being
the carrier's life. Under steady state conditions,

$$I\alpha\beta = \Delta n/\tau, \qquad (6)$$

Because signal voltage V_s of the photoconductive detector
forms a direct ratio with $\Delta\sigma/\sigma$ (σ is the material's con-
ductivity), in most situations $\Delta\sigma/\sigma$ is mainly determined
by $\Delta n/n$. Therefore,

$$V_s \propto \Delta\sigma/\sigma \propto I\alpha\beta\tau/n. \qquad (7)$$

It can be seen that increasing the incident radiation intensity,
using the radiation integrating cavity to raise the absorption
coefficient and using high quantum yield material as well as using
high resistance material or decreased operating temperature to
reduce the background carrier concentration of the detecting

6

materials are all beneficial to strengthening the output signals of the photoconductive detector. Control of the compound mechanism to lengthen the carrier's life no doubt can also increase the signals. However, this takes sacrificing the fast speed response of the detector as the premise and it must be weighed and considered based on the utilization requirements.

At present, the applications of the non-intrinsic photoconductive detector which uses Ge and Si as the base materials are quite widespread. The impurity activation energy in Ge is distributed in the 0.01-0.35 electron volt range, the cut-off wavelength of the response is 3-120 micron, the impurity activation energy in Si is 0.04-0.55 electron volts and the cut-off wavelength of the response is somewhat shorter. Use of the neutral donor captured electron D-state (or neutral acceptor captured hole A+ state) as well as the Rydberg state newly developed detecting devices makes it possible to extend the response wavelength to 0.5 micron. Although the sensitivity of photoconductive detector which is based on the absorption of n type InSb free carriers is inferior to that of the refrigeration type resistance radiation meter, yet its response is fast, its use is convenient and thus it has been given serious attention. Recently, research on the HgCdTe free carrier absorption photoconductive detector can hope to have increases in the area of detection performance. See Table 2 for the development levels of various photoconductive detectors.

(1) 种　　　类	(5) 响应波长范围（微米）	(6) 响应时间	响应性能 (11)
非本征 Ge (2)		(7)	
Ge:Cu	2—30	典型值100毫秒，重补偿材料有可能达1毫微秒	NEP~2.5×10^{-13} 瓦·赫$^{-\frac{1}{2}}$ (12)
Ge:Ga	30—120		NEP~6×10^{-17} 瓦·赫$^{-\frac{1}{2}}$ (13)
非本征 Si (3)			
Si-As(<20K) (4)	1—23	同上 (8)	D*~2.5×10^{10} 厘米·赫·$\frac{1}{2}$瓦$^{-1}$ (14)
Si-As, Si-P, Si-Sb 中D-态 (1.6K)	100—500	1毫微秒	NEP~10^{-14} 瓦·赫$^{-\frac{1}{2}}$ (15)
GaAs			
(4—6K)	100—350	10毫微秒(9)	NEP~4×10^{-14} 瓦·赫$^{-\frac{1}{2}}$ (16)
InSb			
(2K)	200—3000	200毫微秒 (10)	NEP~5×10^{-14} 瓦·赫$^{-\frac{1}{2}}$ (17)

Table 2 Performances of typical photoconductive detectors
[2].

> Key: (1) Type; (2)-(3) Non-intrinsic; (4` ,-state in
> Si-Sb; (5) Range of response wavele :h (micron);
> (6) Response time; (7) Typical val\ is 100
> milliseconds, repeat compensation n , ial can
> reach 1 nanosecond; (8) The same as ,ove, 1
> nanosecond; (9)-(10) Nanosecond; (11) Response
> performance; (12)-(17) Watts·hertz.

3. The Transrectification Detector

The transrectification detector with far-infrared spectral
region is actually an extended development of the microwave
detecting device. It can respond to incident electromagnetic
radiation induced current and can put out signals using certain
nonlinear detection effects. Most transrectification detectors
use the point contact structural form and the area control of
the contact node points is within several cubic micron. This
type of structural design can decrease the value of the device
itself and the parasitic capacity and not cause a serious
bypass device current. However, the stability of the point
contact structure is poor and its operating life is short. The
response time of the transrectification device is very short
and it is especially suitable for utilization situations with

8

very high modulation frequency or as the mixer in a heterodyne detection system.

As a device for video frequency detection or heterodyne mixing detection, the longest structural utilization time of the metallic semiconductor contact is between W and P-Cu and various semiconductor materials (Si, Ge, GaAs, InSb). This type of structure possibly has many detecting mechanisms, yet in the application of the far-infrared spectral region, most are of the Schottky barrier type. The selection of the material is determined by the application, yet up until recently there were still no quantitative results to appraise which type of material as well as which doping level was the ideal state. In recent years, use of the electron beam etching technique has enabled the Schottky barrier diode and "Super Schottky" diode (using superconducting metal to replace the regular metal for making the contact wire) to have successful reports. There has also been widespread research on another transrectification detector with an MIM structure. Its nonlinear electronic properties are based on the results of electron tunnel effects. The Josephson junction has a broad future in the field of far-infrared detection applications. The interaction of its internally produced oscillating current and current induced by external radiation reveal many unique properties. Because of the Josephson junction oscillating superconductive current's intrinsic inductance and superconductor characteristics, when the quantum energy of the incident radiation exceeds the super-conductor's energy gap, the strength of this type of effect weakens and inferring from the basic parameters of existing superconductor material, the Josephson junction is mainly suit-able for radiation detection of wavelengths above 200 micron. Moreover, devices with point contact structures are the most sensitive. See Table 3 for the development levels of the various transrectification detectors.

9

(1) 类 型	(6) 材 料	(9) 响应波长(毫米)	(10) 输入耦合方式	(18) 响应率(伏·瓦⁻¹)	(19) 视频 NEP(瓦·赫⁻¹)
(2) 金属-半导体点接触 (300K)	(7) 金属-Ge W-GaAs	1 0.337	(11) 过模波导 (12) 触须天线	10^4	3×10^{-4} 2×10^{-8}
(3) 光刻肖脱基二极管 (300K)	(8) n型 GaAs	0.496 0.119	(13) 触须天线 (14) 触须天线	10 0.4	10^{-6} 10^{-7}
(4) 金属-金属点接触 (300K)	W-Co W-Ni	0.337 0.337—0.389	(15) 触须天线 (16) 触须天线	1 10^{-1}	
(5) 点接触约瑟夫森结 (≤4K)	Nb-Nb	2.5	(17) 触须天线	5×10^5	3×10^{-15}

Table 3 Performances of typical transrectification detectors [2].

Key: (1) Type; (2) Metal-semiconductor point contact;
(3) Photoetched Schottky diode; (4) Metal-metal
point contact; (5) Point contact Josephson
junction; (6) Material; (7) Metal; (8) Type;
(9) Response wavelength (mm); (10) Input coupling
mode; (11) Excess mode waveguide; (12)-(17) Cat-
whisker antenna; (18) Speed of response (volts·
watts⁻¹); (19) Video frequency NEP (watts·hertz⁻¹/²).

III. Transmission Problems

The far-infrared spectral region can be understood as the
region of overlapping of the classical optical technique and the
classical microwave measure. The difficulty of the effective
transmission measure and coupling mode of far-infrared radiation
is: the waveguide is commonly taken as the major means of micro-
wave transmission. Thus the resistance loss of the waveguide
and the relaxation loss of the dielectric waveguide is due to
the fact that the rise of the operating frequency has very great
changes in the far-infrared region. Aside from this, when the
operating wavelength is shorter than 2 millimeters, the process-
ing of the small-sized waveguide as well as the assembly of the
functional elements both have serious difficulties. Although
the excess mode waveguide to a certain extent can alleviate the
loading requirements in the areas of loss and size, yet the

10

radiation field distribution of the waveguide section is quite complex and there are many difficulties caused by mode type mixing. The situation is more serious when counting chromatic dispersion. Therefore, the development of the directional transmission technique of the structure has already become the most hopeful choice of the far-infrared spectral region. However, not counting the pure light ray optical design of the wave effect, it is necessary that the linearity of the optical element be more than two quantity levels higher than the operating wavelength. For example, for a 1 millimeter wave, if the diameter of the lens or reflector at the least is not smaller than 100 millimeters, this can guarantee that the system has high performance. However, it is naturally inconvenient to assemble such a large element on a laboratory instrument and it is also not practical to use on an astronomical telescope for the same reasons. Therefore, well known microwave measures and optical methods encounter hard to overcome problems in the far-infrared region. In order to resolve the transmission and coupling problems, submillimeter wave optics and quasi-optics were produced. Martin and Lesurf [3], based on the transmission characteristics of Gaussian light beams, implemented the optical method for the far-infrared spectral region. The quasi-optical double beam interferometer spectrometer has a designed structure which is compact, performance is excellent and it can effectively transmit far-infrared radiation. The size of the entire system is about 200 millimeters and the maximum optical path difference is 40 millimeters which is equal to a resolving power of 0.1 centimeters^{-1}.

IV. Coupling Structure

As mentioned above, when the traditional optical and microwave techniques are directly used for the detection of far-infrared radiation, they encounter difficulty. The photoconductive detector is a type of mixer with excellent performance but its response is a little slower. As nonlinear elements, the

Schottky barrier diode and MIM junction have the advantages of
relatively large bandwidths and room temperature operation.
However, the volume is very small and requires a certain type
of feed structure so as to effectively couple the energy to the
diode. When the operating wavelength is reduced, due to the
skin effect, the resistance loss of the metal waveguide becomes
very large and therefore, in a broad sense, the antenna is the
best coupling structure for far-infrared radiation. To date,
the far-infrared antennas which have been used with relative
success is the tungsten cat-whisker (Fig. 1). With the addition
of an angle reflector, we can improve the directionality of the
antenna (Fig. 2). There is also the double angle conical
cavity designed by Gustincic et al (Fig. 3).
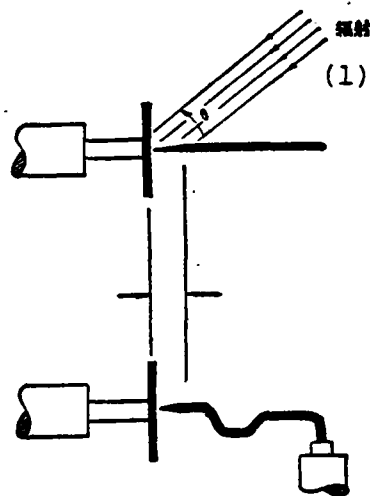
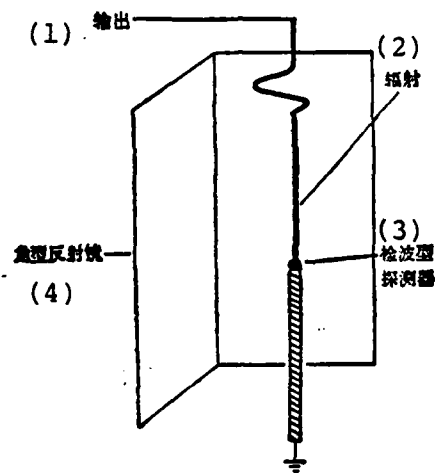Fig. 1 The cat-whisker antenna.
Key: (1) Radiation.

Fig. 2 The free space antenna.
Key: (1) Output; (2) Radiation; (3) Transrectification detector; (4) Angle reflector.
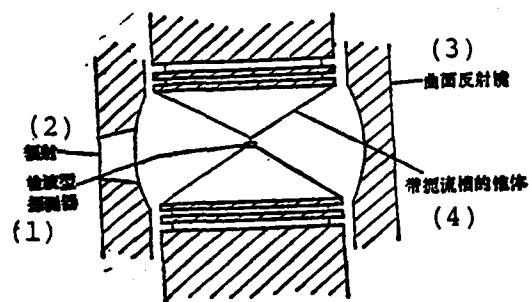

Fig. 3 The double angle conical cavity.
Key: (1) Transrectification detector; (2) Radiation; (3) Curved surface reflector; (4) Cone with choke groove.

The various coupling techniques are still in the early stages of development and we are still unable to make quantitative comparisons of their performances. The greatest drawbacks of this type of antenna are: (1) the antenna model very much resembles the common long-wire antenna. When the operating wavelength is shorter than 2 millimeters, the effective area of the antenna is reduced (in direct ratio to λ^2) and the material

13

characteristics of the tungsten in this spectral region cause the performance of the nonlinear diode to noticeably worsen; (2) it uses the point contact mode and therefore the mechanical stability is poor; (3) the directionality is not good.

The improvements already made are the use of the micro-electronic technique to set the plane antenna in the middle of the dielectric to make it into a sandwich bread shape. Figure 4 is a schematic of the Schwarz V plane antenna set into a quartz medium.
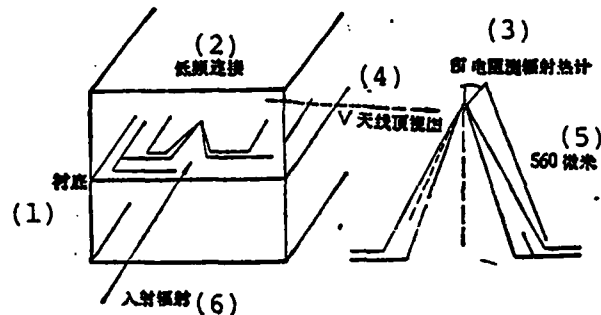

Fig. 4　The infrared V antenna.
　　　　Key: (1) Substrate; (2) Low frequency connection;
　　　　　　 (3) Bi resistance radiation thermometer;
　　　　　　 (4) Top view of V antenna; (5) 560 micron;
　　　　　　 (6) Incident radiation.

It has single lobe antenna characteristics, high gain, wide frequency band and the mechanical stability is far better than that of the point contact device. This V antenna can be coupled with various types of detectors [4]. When it is used in conjunction with the Bi resistance radiation thermometer, in the 119 micron area, measured antenna gain g is 8 decibels [5,6]. Based on the same principles, the integration of the manufactured parallel wire transmission line and the 400 unit Bi resistance radiation thermometer has already been successful. The total operating area is 1 centimeter^2, the coupling rate in the 1 millimeter area is 60%, the device's detecting rate is

$D^* \cong 4 \times 10^8$ centimeters·hertz$^{1/2}$·watts^{-1} and the response time is 2×10^{-7} seconds (Fig. 5). Research on the integration of the Schottky barrier diode and the SIS detector is being carried out [7].
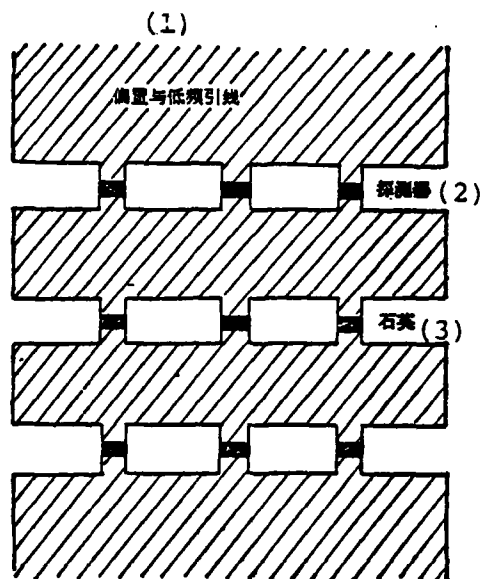

(1)

偏置与低频引线

探测器(2)

石英(3)

Fig. 5   Integration of the parallel wire transmission line and the 400 unit Bi resistance radiation thermometer.

　　　Key: (1) Bias and low frequency lead wire; (2) Detector; (3) Quartz.

V.   Conclusion

The far-infrared detecting technique is a comprehensive utilization technique and the research developments in inter-related disciplines will provide it with new mechanisms and methods. Research on strengthening the interaction of the far-infrared radiation and substances thus seeks even more sensitive and functional detectors, perfecting the quasi-optical system

15

design theory so as to satisfy ever widening utilization requirements, using microprocessing techniques, developing plane array detecting devices and gradually realizing integration with antennas, waveguides and radiation sources. All of these are not too distant development directions worthy of serious attention in research on far-infrared detecting techniques. It can be predicted that research developments on far-infrared detecting techniques will carry with them even wider applications.

References

[1] E.D. Dalik, J. Opt. Soc. Am., 67(1977), 857-865.

[2] T.G. Blaney, Infrared and Millimeter Waves, Academic Press, 1980, Vol. 3, 34-49.

[3] D.H. Martin et al, Infrared Phys., 18(1978), 405-412.

[4] T.L. Hwang et al, Appl. Phys. Lett., 31(1977), 101-104.

[5] D.B. Rutledge et al, IEEE J. Quantum Electron., QE16 (1980), 508-516.

[6] T.L. Hwang et al, Appl. Phys. Lett., 34 (1979), 9-11.

[7] D.B. Rutledge et al, IEEE J. Quantum Electron., QE17(1981), 407-414.

END

FILMED

10-84

DTIC